

2.—CONTRIBUTIONS TO THE MINERALOGY OF WESTERN AUSTRALIA

(With One Plate, xxiii., and Three Figures.)

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Series II.

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(1.) HYDROTHORITE (Sp. nov.), WODGINA, N.W. DIV.

Some years ago the author described a series of three radioactive minerals found in the tantalite-bearing pegmatite vein on M.Ls. 86 and 87 at Wodgina\* (Lat. 21° 12', Long. 118° 38'). These minerals were all hydrous silicates of thorium, uranium and lead, and were so related that two of them appeared to have been derived by weathering from the third, Mackintoshite, which was thought to be a primary constituent of the pegmatite. A fourth mineral in the series has now been detected, and this the author proposes to name Hydrothorite. The compositions and relationships of these minerals are—

- (1.) Mackintoshite :  $3\text{ThO}_2 \cdot 4\text{UO}_2 \cdot \text{PbO} \cdot \text{CaO} \cdot 8\text{SiO}_2 \cdot 24\text{H}_2\text{O}$ .
- (2.) Thorogummite :  $3\text{ThO}_2 \cdot 4\text{UO}_3 \cdot \text{PbO} \cdot \text{CaO} \cdot 8\text{SiO}_2 \cdot 21\text{H}_2\text{O}$ .
- (3.) Pilbarite :  $\text{ThO}_2 \cdot \text{UO}_3 \cdot \text{PbO} \cdot 2\text{SiO}_2 \cdot 4\text{H}_2\text{O}$ .
- (4.) Hydrothorite :  $\text{ThO}_2 \cdot \text{SiO}_2 \cdot 4\text{H}_2\text{O}$ .

During 1926 the tantalite vein on M.L. 86 was reopened in search of further tantalite by an adit at a depth of about 25ft. In this adit all the above minerals were encountered, the last named in greatest abundance and in masses up to 7 cm. (3in.) in diameter. It was associated with albite (more or less weathered), quartz, spessartite, manganotantalite and weathered lithiophilite.

The visible and easily determined distinctions between the four related minerals are—

	Mackintoshite	Thorogummite	Pilbarite	Hydrothorite
Texture ...	Glassy	Subvitreous, dense.	Earthy, porous, mod. tough	Earthy, very porous, fragile.
Hardness ...	4	3.5	3-2.5	1-2
Colour in mass ...	Black	Bright yellow	Orange	Pale pink or cream
Density ...	4.31-4.45	4.13	4.68	?
Light refraction	Isotropic n, ?	Isotropic n, 1.617†	Isotropic n, 1.74	Isotropic n, 1.638‡

\* Geol. Surv. W.A. Bull. 48, pp. 9-21.

† Mean value. It ranges from 1.609 to 1.624, varying with hydration.

‡ Determined on the powder which was analysed.

No traces of crystalline structure have been observed on any of the minerals, except in rare doubtful cases on Pilbarite. All four prove to be highly radio-active when examined with a scintilloscope.

A nodule of hydrothorite of uniform colour and appearance and weighing about 6 grammes was taken for analysis. Attempts to determine its density failed owing to the rapidity with which it broke off in small flakes immediately it was immersed in distilled water, the result apparently of rapid imbibition. The colour of the mineral when dry was Ridgway 18''f, *i.e.*, between "pale pinkish buff" and "cartridge buff." This colour was considerably altered by wetting, the wet mineral matching Ridgway 15f, "pale yellow orange." In mass it was opaque, but under a microscope the fine powder was transparent and isotropic.

The thoroughly air-dried mineral was readily powdered in an agate mortar, to which it showed a strong tendency to adhere, as well as giving a sticky resinous feel between the fingers.

The results of the analysis made \* are given in the following table alongside those of the type minerals which most nearly approach it in composition, *viz.*, Thorite, Orangite, and Uranothorite, the last two being simply varieties of the first.

Type mineral	Thorite.	Orangite.	Uranothorite.	Hydrothorite.
Locality	Lovo, Norway.	Brevik, Norway.	L. Champlain, U.S.A.	Wodgina, W.A.
SiO <sub>2</sub>	18.98	17.52	19.38	15.77
ThO <sub>2</sub>	57.91	71.65	52.07	57.79
Ce <sub>2</sub> O <sub>3</sub>	...	...	...	.24
Y <sub>2</sub> O <sub>3</sub>	...	...	...	.73
UO <sub>2</sub>	1.62	Nil	Nil	Nil
UO <sub>3</sub>	...	1.20	9.96	2.98
Fe <sub>2</sub> O <sub>3</sub>	3.40	.31	4.01	Nil
Mn <sub>2</sub> O <sub>3</sub>	2.39	.28	...	trace
Al <sub>2</sub> O <sub>3</sub>	.06	.17	.33	.88
PbO	.80	.88	.40	1.25
CaO	2.58	1.59	2.34	1.65
MgO	.36	...	.04	.60
K <sub>2</sub> O	.14	.14	.11	Nil
Na <sub>2</sub> O	.09	.33	...	Nil
H <sub>2</sub> O	9.50	6.14	11.31	15.18
CO <sub>2</sub>	...	...	...	1.50
P <sub>2</sub> O <sub>5</sub>	...	...	...	1.33
Insol.	1.70	...	...	Nil
	99.53	100.14	99.95	99.90
Density	4.8	5.19	4.13	?
Ref. index	1.686	1.693	?	1.638

The analysis and microscopic examination of the analysed material indicate that about 90 per cent. of it consists of a light amber coloured and transparent (under the microscope), isotropic, probably amorphous, substance with a refractive index of 1.638, and a composition expressed by the formula ThSiO<sub>4</sub>. 4H<sub>2</sub>O. This substance differs from typical thorite and its varieties by the much higher water content and lower refractive index. It is worthy of specific rank under the name Hydrothorite.

Intimately admixed with it in small quantities are a carbonate, a phosphate, and probably a second silicate. Attempts to determine these specifically were not successful, but there are reasons for believing they include

\* Only vessels of quartz and platinum were used. Except where otherwise stated all analyses of W.A. minerals in this paper were made by the Author.

dolomite, kaolin and autunite. Auerlite, an ill-defined and doubtfully homogeneous mineral from North Carolina, is thought to be a compound silico-phosphate of thorium. Possibly some of the phosphorus of the Wodgina mineral is present in this form, or as one of the recently described lead uranium phosphates, parsonsite, dumontite or dewindtite.

The chemical properties determined are as follow:—Part of the water is very loosely held so that differences of about one per cent. in the total water are noted under different conditions of atmospheric temperature and humidity. Drying for two hours at 100° removes 9.12 per cent. of water. Of the remaining 6.06 per cent. about 5 per cent. is removed at 600° C., the balance at a bright red heat (about 800°).

The powdered mineral is freely attacked by warm and moderately strong mineral acids. The most rapid and complete attack is by warm 10N HNO<sub>3</sub>, which leaves a granular residue consisting only of hydrous silica.

In nature the chemical change in Mackintoshite under weathering is first an oxidation of UO<sub>2</sub> to UO<sub>3</sub>, then a progressive removal of lime, uranium, lead, silica and water, leaving ultimately a simple hydrous thorium silicate—Hydrothorite.

The type specimen is in the Western Australian Museum, and a co-type has been sent to the British Museum.

## (2.) LITHIOPHILITE AND PURPURITE, WODGINA, N.W. DIV.

In Series 1 of these contributions the Author described a boulder of lithiophilite (LiMnPO<sub>4</sub>) from a somewhat indefinite locality approximately 20 miles south-west of Wodgina. Further information regarding the find indicates that the more exact position is on Yandeyarra Station, a little south of Mt. Francisco. No further specimens have been obtained from this place.

Lithiophilite has now been found to be rather plentiful at Wodgina itself, many specimens in various stages of alteration having been obtained in Lewis' pegmatite vein, one mile north of the township, and in the manganotantalite bearing pegmatite on Mineral Lease 86, as well as in the adjacent detrital material. Lithiophilite weathers rather readily by loss of lithia, assumption of water and oxidation of FeO and MnO to Fe<sub>2</sub>O<sub>3</sub> and Mn<sub>2</sub>O<sub>3</sub> yielding Purpurite, H<sub>2</sub>O.(Mn, Fe)<sub>2</sub>O<sub>3</sub>.P<sub>2</sub>O<sub>5</sub>. Still further alteration gives rise to Psilomelane and Limonite. These effects are observable in all stages at Wodgina, the mineral gradually darkening in colour from honey yellow, or pale grey, to brown, and finally black, the cleavages becoming more obscure, and the density falling through all stages from 3.4 to 2.8. The black stage is locally known as "Plumbite," a term of unknown origin, or as "Likem," because the detrital fragments are like in appearance to detrital manganotantalite, at present in commercial demand and keenly sought for.

The freshest lithiophilite so far found in the immediate vicinity of Wodgina is that occurring on Lewis' property, one mile west of the tantalite mine. The owner states that he has uncovered already one ton of the mineral in three seams in a pegmatite vein traversing greenstone schists of the Warrawoona Series (older Pre-Cambrian) and emanating probably from the adjacent Pre-Cambrian granite. An average sample of this ton contained—

Li<sub>2</sub>O, 1.50 per cent.; P<sub>2</sub>O<sub>5</sub>, 35.03 per cent.; Insoluble, 3.38 per cent.

The low figure for lithia indicates extensive alteration.

The least altered fragment was selected for complete analysis. It belonged to a single crystal individual and showed two imperfect cleavages, one (001) better than the other (010). It was fairly tough with a hardness of  $4\frac{1}{2}$ . The colour of the mass was mottled, owing to irregular oxidation, the colour varying from brownish black to dark red brown (1'''m to 1''m Ridgway) with minute areas much paler, about honey yellow.\* The cleavages were continuous and not interrupted by the variations in colour. The colour of the powder was wood brown (17'''). Its density was 3.23.

After moistening with  $H_2SO_4$  it gave a strong lithium flame, but did not etch glass, thus differing from triplite,  $MnF.MnPO_4$ . By a rigid analytical method Mr. D. G. Murray, of the Government Laboratory, has proved the absence of fluorine from the Wodgina mineral. The mineral in powder dissolved readily in warm strong HCl with evolution of some chlorine. It was much less soluble in other acids than the quite unweathered lithiophilite from Yandeyarra, being only very slowly attacked by hot dilute (5E) $H_2SO_4$ , except in the presence of a reducing agent such as  $H_2SO_3$  or  $FeSO_4$ . It dissolved slowly in hot dilute (5E) $HNO_3$  leaving a slight dark brown residue, apparently an  $MnO_2$  compound.

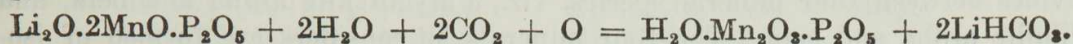
The results of the analysis are given in the table below in column A, those in column B being recalculated after deducting moisture and insoluble in acids, mainly quartz. In column C are given the theoretical figures for lithiophilite, and in column D those for purpurite, in both cases the ratio of iron to manganese found in the Wodgina mineral being maintained.

	A.	B.	C.	D.
	Altered lithiophilite Wodgina.		Theory Lithio- philite.	Theory Purpu- rite.
$P_2O_5$	... .. 42.77	42.98	45.23	44.65
FeO	... .. 4.23	4.25	7.07	...
$Fe_2O_3$	... .. 2.50	2.51	...	7.75
MnO	... .. 22.77	22.88	38.19	...
$Mn_2O_3$	... .. 13.38	13.44	...	41.94
$Co_2O_3$	... .. .10	.10	...	...
CaO	... .. 3.30	3.32	...	...
MgO	... .. .84	.84	...	...
$Li_2O$	... .. 4.48	4.50	9.51	...
$Na_2O$	... .. .15	.15	...	...
$K_2O$	... .. .05	.05	...	...
F	... .. Nil	Nil	...	...
$H_2O+$	... .. 5.62	5.65	...	5.66
$H_2O-$	... .. .06	...	...	...
Insoluble...	... .. .42	...	...	...
	100.67	100.67	100.00	100.00
D.	... .. 3.23	3.24	3.45	3.10 ±

The figures for the relative states of oxidation of the manganese and iron are not exact owing to imperfections in analytical methods. Practically the whole of the water is removed at about  $550^\circ$  and fusion takes place at about  $800^\circ$ .

\* Later specimens received from Wodgina consist of a somewhat less altered lithiophilite. One from the tantalite vein on M.L. 86 has a density of 3.36 and one from Lewis' vein a density of 3.23. Both show large cores, up to 5 mm. diameter of dull, yellow lithiophilite shading off through amber brown to brownish black.

It would appear then that this material from Wodgina is not homogeneous but consists of lithiophilite, partly (about one-third) altered by weathering into pseudomorphous purpurite, the alteration spreading inwards from the most prominent cleavage planes in accordance with the following equation—



This is the first record of the occurrence of Purpurite in Australia.

The only associated minerals recorded from Lewis' vein so far are albite, microcline, apatite, spessartite, and quartz. On the tantalite mine the following have been noted in contact with it: Albite, quartz, muscovite, spessartite, manganotantalite, hydrothorite, thorogummite, apatite and autunite.

### (3.) AUTUNITE, WODGINA, N.W. DIV.

Included in a fine suite of specimens recently brought to Perth by Mr. G. Skuthorpe from the Tantalite Mine (M.L. 86), at Wodgina, were some showing lithiophilite and thorogummite in juxtaposition. On some of the contacts, and in cracks in both minerals near their junction, thin crusts were observed of a finely scaly, soft mineral, varying in colour from Ridgways 25d to 31d (pale greenish yellow to light yellow green). The general appearance and association with a phosphate (lithiophilite) and a uranium mineral (thorogummite) suggested autunite ( $\text{CaO} \cdot 2\text{UO}_3 \cdot \text{P}_2\text{O}_5 \cdot 8\text{H}_2\text{O}$ ). Optical tests confirmed this surmise, the bi-refringence of the flat scales being very small, and the mean refractive index being determined by immersion as 1.575. The recorded data for the optical properties of a basal section of autunite are Nm, 1.575; Ng, 1.577; Y = b, Z = a.

This is the first time that autunite has been discovered in Western Australia.

### (4.) SPESSARTITE, WODGINA, N.W. DIV.

Crystals and fractured fragments of a pale coloured garnet have been found for some time past in the alluvial gravels carrying cassiterite and manganotantalite at Wodgina. Recently the same mineral has been found *in situ* in the tantalite lode (an albite pegmatite vein) on M.Ls. 86 and 87. In the latter it appears as very pale pink to light brownish red crystals. The best specimens, however, have come from adjacent soil and gravels. These latter are crystals or fragments up to about 3cm. in diameter. The common form is the dodecahedron (110) bevelled by a trapezohedron (211). Comparatively rare are crystals of the trapezohedron (211) with faint truncating of the solid angles by the dodecahedron (110). The translucency varies in different crystals from a limiting thickness of 1 mm. to one of 5 mm.\* The colour is difficult to match with Ridgways standards, but for the most part lies approximately between 15" and 15"d (cinnamon to light pinkish cinnamon). Most noticeable is the very thin, almost pure black coating of psilomelane, which completely covers a few of the detrital crystals.

A typical detrital specimen of a little over 6 grammes in weight, and having a density of 4.16, was analysed with the following results—

	SiO <sub>2</sub>	TiO <sub>2</sub>	Al <sub>2</sub> O <sub>3</sub>	Fe <sub>2</sub> O <sub>3</sub>	FeO	MnO	CaO	MgO	Total
Per cent. ...	36.03	.03	20.84	traces	4.18	37.79	.81	.19	99.87
Mols. ...	6,001	4	2,044	...	582	5,327	145	47	...

from which the ratios MO:M<sub>2</sub>O<sub>3</sub>:SiO<sub>2</sub> are calculated to be 3.01:1.01:2.97.

Microscopic crystals of spessartite have previously been detected in a schist from the Eyre Range. S.W. Div.

\* Maximum thickness permitting a perceptible amount of daylight to pass through.

## (5.) PILOLITE, WADARA HILLS, N.W. DIV.

According to Doelter\*, who gives the latest and most complete account of the Palygorskite group of minerals, this group comprises most of the so-called "mineral leather" and "mineral cork" (mountain cork) which he divides between four mineral species, viz., Palygorskite alpha and beta, and Pilolite alpha and beta. The four minerals he considers are formed of isomorphous associations in four different proportions of the compounds  $2\text{H}_2\text{O}\cdot 2\text{MgO}\cdot 3\text{SiO}_2 + 2\text{H}_2\text{O}$  and  $3\text{H}_2\text{O}\cdot \text{Al}_2\text{O}_3\cdot 4\text{SiO}_2 + 2\text{H}_2\text{O}$ . In this series the palygorskites are at the more aluminous end, the pilolites at the more magnesian end. Further reference to the constitution of the members of the group will be made after considering the local mineral.

In sinking a well on Pastoral Lease 3367/97, between the Wadara Hills and the Rabbit Proof Fence (Lat.  $23^\circ 0'$  S., Long.  $121^\circ 3'$  E.) masses of almost pure white spongy material were found at a depth of about 70 feet in sediments including sandstones, clays, and travertine with common opal. One of the spongy masses was examined in the Government Laboratory and was found to approximate to Doelter's alpha-pilolite.

It was a subrounded mass about 8 x 4 x 3 inches (20 x 10 x 7.5 cm.) in size, very light and porous in texture, and quite tough, breaking and cutting like cork. For the most part it was pure white in colour, but slight stains of limonite and psilomelane occurred in places.

For analysis, some of the whitest material was coarsely crushed, and washed well with distilled water to remove associated traces of salt and epsomite, then air-dried till constant in weight, and ground fine. The analytical results are given below with comparative figures for similar minerals from Scotland, Chile and New Mexico—

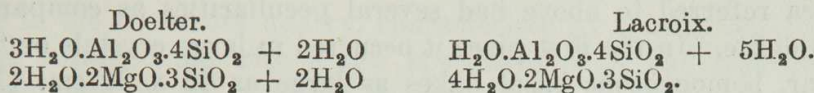
	Beta Paly- gorskite Scotland.	Alpha Pilolite Chile.	Alpha Pilolite New Mexico.	Pilolite Wadara Hills.	Pilolite Wadara Hills.
	%	%	%	%	mols.
$\text{SiO}_2$	... 54.37	54.72	60.97	55.12	917
$\text{Al}_2\text{O}_3$	... 11.27	7.95	} 9.71 {	9.67	95
$\text{Fe}_2\text{O}_3$	... .21	2.22		1.25	8
$\text{FeO}$	... 1.09	.92	...	...	...
$\text{MnO}$	... .33	.43	...	trace	...
$\text{MgO}$	... 9.49	11.81	10.00	10.55	261
$\text{CaO}$	... .98	.02	.22	Nil	...
$\text{H}_2\text{O} + 100^\circ$	13.15	6.81	} 19.14 {	13.14	729
$\text{H}_2\text{O} - 100^\circ$	9.26	15.12		10.48	582
	<u>100.15</u>	<u>100.00</u>	<u>100.04</u>	<u>100.21</u>	

Almost the whole of the combined water was driven off by two hours' heating at about  $550^\circ\text{C}$ .

The mineral selected for analysis was examined under the microscope and found to be practically uniform, at least 99 per cent. being apparently uniaxial with a low birefringence, and No equal to 1.512. The other 1 per cent. was finely scaly with higher birefringence, possibly kaolinite. The hardness of the analysed material was about 1.5 and the true density, determined with methylene iodide, was 2.10. The microscopic structure was elongated scaly rather than filamentous, as described for many minerals of this group. The scales were somewhat wrinkled and twisted, which accounts for the appreciable toughness of the mineral in mass.

\* Handb. der Mineralchemie, 11 (2) 670.

Having analysed the mineral, consideration was given to Doelter's theory of its constitution, as well as to that of Lacroix, which is almost identical.\* Both consider the series to consist of isomorphous intergrowths of two end members as follow:—



Our present knowledge of isomorphous displacements makes it certain that neither of these suggested pairs could have such identical space lattices as to enable them to displace one another in such varied proportions as are needed to conform with the published analyses of minerals of the series. To do this there must be (with certain rare exceptions not involved here) an identical number of elements in each space lattice, which demands † an identical number of atoms in each solid molecule, a condition very far from being satisfied by either of these suggestions.

The author has found that by taking the halloysite molecule as a basis, and deriving therefrom a corresponding isomorphous magnesium silicate (conveniently called here picrocollite) by substituting MgSi for Al<sub>2</sub>, a series can be built up corresponding very closely to most of the published analyses of palygorskite and pilolite. The two primary molecules are—

Halloysite	... ..	... ..	$\text{H}_4\text{Al}_2\text{Si}_2\text{O}_9 + 2\text{H}_2\text{O} = (\text{Hal}).$
Picrocollite	... ..	... ..	$\text{H}_4\text{MgSi}_2\text{O}_9 + 2\text{H}_2\text{O} = (\text{Hmg}).$
Alpha-palygorskite is then	... ..	Hal + Hmg	$(\text{MgO} \cdot \text{Al}_2\text{O}_3 \cdot 5\text{SiO}_2 \cdot 8\text{H}_2\text{O}).$
Beta-palygorskite	... ..	Hal + 2Hmg	$(2\text{MgO} \cdot \text{Al}_2\text{O}_3 \cdot 8\text{SiO}_2 \cdot 12\text{H}_2\text{O}).$
Wadara Hills pilolite close to	... ..	Hal + 3Hmg	$(3\text{MgO} \cdot \text{Al}_2\text{O}_3 \cdot 11\text{SiO}_2 \cdot 16\text{H}_2\text{O}).$
Alpha pilolite	... ..	Hal + 4Hmg	$(4\text{MgO} \cdot \text{Al}_2\text{O}_3 \cdot 14\text{SiO}_2 \cdot 20\text{H}_2\text{O}).$

The formula recently ascribed by Ross and Shannon‡ to montmorillonite (the chief constituent of most bentonite) is  $\text{MgO} \cdot \text{Al}_2\text{O}_3 \cdot 5\text{SiO}_2 \cdot n\text{H}_2\text{O}$ , which is exactly Hal + Hmg. There is therefore probably a close relationship in constitution between palygorskite and montmorillonite, though their state of aggregation appears at first sight so dissimilar.

This is the first record of the occurrence of this group in Western Australia. W. F. Petterd recorded the presence of pilolite at Mt. Bischoff, Tasmania, in 1910. H. Y. L. Brown in 1908 noted the occurrence of "mountain cork" at Sailors' Gully near Gawler, South Australia; whilst as long ago as 1867 an Intercolonial Exhibition pamphlet referred to "mountain leather" at Tarilta, Victoria. No analyses of any of these can be found.

### (6.) LEPIDOLITE (UNIAXIAL AND BIAXIAL) AND MUSCOVITE, LONDONDERRY, CEN. DIV.

In the annual report of the Geological Survey for 1897, T. Blatchford and the Author made the first record of the occurrence of lepidolite in large "books" in a pegmatite vein four miles N.W. of Londonderry. This is in an area sometimes referred to as Grosmont, from the name of an adjacent gold mine (Lat. 31° 5', Long. 121° 7'). Subsequently in 1902 the author published an analysis of the mica.§ Some details of its occurrence were given by T. Blatchford in 1913.|| Later a second analysis was made by the author but not published: the figures were, however, communicated to A. N. Willchell and used in his "Studies in the Mica Group."¶ Altogether some tons

\* Min. de la France, IV., 745.

‡ Jour. Amer. Cer. Soc. IX., 77-96 (1926).

§ G.S.W.A., Bull. 53, p. 19.

† As recognised long ago by Tschermach.

‡ G.S.W.A., Bull. 6, p. 57.

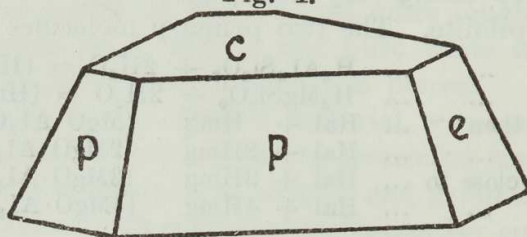
¶ Am. J. Sci. 9 (1925), p. 424, 427.

of this mica were quarried, and marketed, most of it being trimmed into rectangular sheets at the mine. Owing to its low fusibility it was ultimately found inadvisable to use the mica as a substitute for muscovite for many purposes, and no demand for it as a source of lithia has ever arisen.

The mica referred to above had several peculiarities as compared with ordinary lepidolite. In the first place it occurred in large crystals or "books," yielding clear, homogeneous basal flakes as large as 40 x 30 cm. (15 x 12 inches), though the average was less, say, 10 cm. square. Secondly, it was optically uniaxial, though all other recorded lepidolites, with the exception of one from Mursinsk, are biaxial, with optic axial angles (2E) ranging from 21° (Elba, Comucci) to 76° (several localities). Finally, it was richer in lithia, 5.83 to 6.15 per cent., than any previously described lepidolite.

Several imperfect crystals of this uniaxial mineral have been observed. One has a hexagonal base, three alternate arrises of which are about half the length of the other three, the diameter being 5 cm. The two basal faces are connected by six rather rough and horizontally striated pyramid faces which (assuming the data for muscovite to apply to lepidolite) are  $p^1 p^2 p^3 p^4 e^1 e^2$ ,  $p$  being (113), and  $e$  (023). See Fig. 1. The striations

Fig. 1.



Crystal of Uniaxial Lepidolite,  
Londonderry.

are due to narrow alternating faces of other steeper pyramids probably (111) and (011). Only approximate angle measurements were possible and these agreed with the figures calculated for muscovite, viz.,  $cp$ ,  $66\frac{1}{2}^\circ$ ;  $ce$ ,  $66\frac{1}{2}^\circ$ . In other specimens a gliding plane is prominent which approximates to  $(-205)$  of muscovite, in one case it is associated with a pressure figure of the typical three-rayed form, one ray parallel to the gliding plane. The hardness of the mineral is 2.5, and its density 2.84. Its colour in thick blocks is maroon or madder brown. In flakes 1 mm. thick it is perfectly transparent with a slight purplish brown tint. Optically it is uniaxial, negative, with  $N_g = N_m = 1.5550$ ,  $N_p = 1.5324$  for sodium light as determined by A. N. Winchell (*loc. cit.*).

Two analyses of this uniaxial mica made at intervals of many years are given in the table below. A determination of the alkalis in a third specimen on another occasion gave  $Li_2O$ , 6.15;  $Na_2O$ , 0.52;  $K_2O$ , 11.12 per cent. The average lithia content in lepidolites from 16 different localities (including five in Western Australia) is only 4.23, the previous highest recorded being 5.88 in a single specimen from Rozena, Moravia. As in the latter, the fluorine is unusually high in the Londonderry mineral.

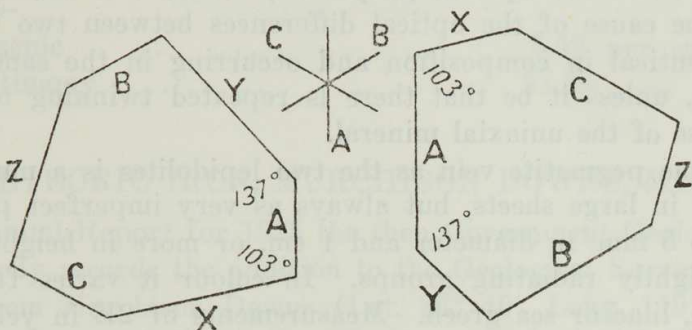
The etching figures, obtained by treatment of the basal plane with hydrofluoric acid, emphasise the hemimorphic structure suggested by the single crystal examined. Two forms of pittings—which are reflections of one another over a vertical plane making an angle of approximately  $22^\circ 30'$  with (010) and possibly symbolised by (150) or (290)—are distributed indiscriminately over a single surface. Their forms and relationships to the percussion figure are shown in Fig. 2. A single similar form has been described



by H. Baumhauer\* as developed by him on the variety of dark brown lepidolite from Mursinsk which has a very small optic axial angle.

Dr. C. O. G. Larcombe and Mr. D. McDougall, of the Kalgoorlie School of Mines, drew my attention to the fact that there was a second variety of lepidolite in the Grosmont quarry, characterised by a large optic axial angle. The latter supplied me with a few specimens of it and informed me that it occurred only in the footwall section of the pegmatite vein close to a narrow vein of topaz, whilst the uniaxial mica is found in the hanging wall section. Both are associated with very coarse microcline-perthite and quartz.

Fig. 2.



Londonderry Uniaxial Lepidolite.

Etching Figures on Basal Plane.

Similarly lettered boundaries are parallel.

This biaxial type is identical with the uniaxial in hardness, density, transparency and colour. It appears, however, to form somewhat smaller (though still at times large) sheets, and on occasion to form coarse aggregates in which several crystal individuals interpenetrate.

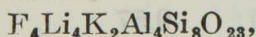
An optical examination revealed the fact that there were marked differences in the magnitude of the optic axial angle in different specimens. Three had identical angles,  $2E = 52^\circ 53'$ , whilst a series of eight other specimens had angles ( $2E$ ) ranging from  $5^\circ 6'$  to  $12^\circ 22'$ . The complete data for two specimens, one with the greatest angle, the other with a small angle, were—

- (1.)  $2E = 52^\circ 53'$ ,  $2V = 33^\circ 18'$  ... Angle Bxa : C =  $1^\circ 20'$   
Ng, 1.557 ; Nm, 1.553 ; Np.?
- (2.)  $2E = 8^\circ 35'$ ,  $2V = 5^\circ 32'$  ... Angle Bxa. : C =  $3^\circ$   
Ng, 1.555 ; Nm, 1.553 ; Np.?

The angles were measured by comparison with a basal section of aragonite under convergent polarised sodium light.

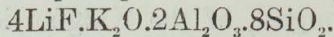
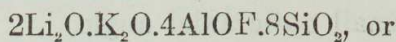
It was expected that a chemical analysis of the mica with the largest angle would reveal differences in composition sufficient to account for the optical differences. The figures given in column (3) below show, however, that there are practically no differences between the two, except in the manganese oxide content, which averages 1.28 in the uniaxial and 0.63 in the biaxial mineral.

It is to be noted that there is more lithia shown in two out of the three analyses than has ever previously been found in lepidolite, whilst there is only one higher value for fluorine recorded, viz., 8.71 in the mineral from Juschakowa in the Urals. These facts indicate that probably the Londonderry mineral is very close in composition to the pure lepidolite molecule, for which the analyses therefore provide a basis of calculation. The formula calculated is—



\* Zeit. Kryst. 51.348 and Pl. VIII., 5.

or in other terms—



In this formula Na is capable of displacing Li to some extent, a displacement often noted in lithium minerals; whilst (OH) usually displaces a small part of the F. The composition of pure lepidolite calculated from the formula is—

Li <sub>2</sub> O	K <sub>2</sub> O	Al <sub>2</sub> O <sub>3</sub>	SiO <sub>2</sub>	F	Total	Less O = F <sub>2</sub>
6.77	10.68	23.11	54.46	8.61	103.63	3.63

Plotting the two minerals on Winchell's graphs (*loc. cit.*) it is found that the biaxial mineral occupies an almost normal position in the relationship of composition to optical properties, whilst the uniaxial mineral is abnormal. The cause of the optical differences between two such minerals, practically identical in composition and occurring in the same vein, is not yet explicable, unless it be that there is repeated twinning on the vertical axis in the case of the uniaxial mineral.

In the same pegmatite vein as the two lepidolites is a muscovite, which never appears in large sheets, but always as very imperfect prismatic crystals from 3 to 5 mm. in diameter and 1 cm. or more in height, arranged in parallel or slightly radiating groups. In colour it varies from colourless to pale mauve, lilac or sea green. Measurements of 2E in yellow light give 77° 48' for the mean of two mauve crystals, and 76° 52' for a green crystal. The composition of a mauve specimen is shown below.

#### ANALYSES OF LONDONDERRY MICAS.

			Lepido- lite. Uniaxial.	Lepido- lite. Uniaxial.	Lepido- lite. Biaxial.	Musco- vite. Biaxial.
Li <sub>2</sub> O	...	...	5.83	5.97	6.37	0.32
Na <sub>2</sub> O	...	...	1.03	2.43	.90	1.19
K <sub>2</sub> O	...	...	11.18	10.31	11.10	10.71
SiO <sub>2</sub>	...	...	51.67	51.00	52.57	45.22
Al <sub>2</sub> O <sub>3</sub>	...	...	23.22	24.13	23.01	37.46
Fe <sub>2</sub> O <sub>3</sub>	...	...	...	...	.08	trace
FeO	...	...	.04*	trace*	Nil	.56
MnO	...	...	1.37	1.20	.63	.71
MgO	...	...	.30	trace	Nil	.38
CaO	...	...	Nil	trace	Nil	.10
H <sub>2</sub> O+	...	...	.44	.22	.59	3.68
F ...	...	...	8.22	7.79	8.26	.73
TiO <sub>2</sub>	...	...	.06	trace	.04	n.d.
BaO, V <sub>2</sub> O <sub>3</sub> , Cr <sub>2</sub> O <sub>3</sub> , Cl	...	...	Nil	Nil	Nil	Nil
			103.36	103.05	103.55	101.06
Less O = F	...	...	3.46	3.28	3.48	.31
			99.90	99.77	100.07	100.75
D. ...	...	...	2.85	2.75	2.83	2.77

Analyst ... .. H. Bowley C. G. Gibson. D. G. Murray. E. S. Simpson

\* May be present as Fe<sub>2</sub>O<sub>3</sub>.

#### (7.) TETRAHEDRITE, KALGOORLIE, CEN. DIV.

In Bulletin 42 of the Geological Survey a description was given of an arsenical fahl ore (tennantite) found rather frequently in small granular masses in the sulphide ore of the Boulder group of gold mines. This mineral contained the following amounts of arsenic and antimony—

	A.	B.
Arsenic	16.87	10.01 per cent.
Antimony	4.30	9.57 ,,

Up till recently no fahl ore had been detected at Kalgoorlie in which anti-mony preponderated over the arsenic. Dr C. O. G. Larcombe has now, however, kindly lent me for description a small (5 x 3 x 2 cm.) but very handsome specimen consisting of coarsely crystallised tetrahedrite from a vugh in one of the deeper levels of the Ivanhoe G.M.

The crystals are imperfect through mutual interference, but range from 5 to 25 mm. along their longest edge. They are a combination of the tetrahedron  $\frac{1}{2}(111)$  with broad bevels made up of an alternating development of two tetragonal trisoctahedra  $\frac{1}{2}(411)$  and  $\frac{1}{2}(211)$ . Measured angles were  $(411):(141) = 60^\circ$  and  $(211):(121) = 33\frac{1}{2}^\circ$ .

The antimony and arsenic contents were determined on a small chip and proved to be—

Arsenic	..	..	..	..	5.58 per cent.
Antimony	..	..	..	..	21.36 „

(8a.) METEORIC IRON, MURCHISON DOWNS, MUR. DIV.

In his Annual Report for 1925 the then Government Geologist (A. Gibb Maitland) briefly records the addition to the Geological Survey collection of a meteorite from Murchison Downs (Lat.  $26^\circ 40'$ , Long.  $119^\circ 0'$  approx.). Through the courtesy of the Acting Government Geologist (T. Blatchford) I am enabled to give a short description of it.

The iron is the smallest complete meteorite yet discovered in the State, weighing only 33.5 grams, with maximum dimensions, 43 x 30 x 10 mm. It shows no recent fracture faces but is entirely covered with the usual fused brown crust of oxides. It is pear-shaped, the narrow end being drawn off to a rather fine point. One side is approximately flat and exhibits a few typical concavities, the other side is convex but grooved.

A small portion of the surface was filed off and an area of about 10 mm. square polished. This on etching exhibited the usual three octahedral sets of kamacite lamellae, not, however, very regularly or plainly developed, probably because the etched section was so close to the fused surface. The lamellae were 0.2 to 0.5 mm. thick, which shows the iron to belong to the "fine octahedrite" (Of) group of Brezina. Typical taenite and schreibersite were visible and a small oval grain of cohenite.

The filings when tested chemically gave a strong reaction for nickel.

(8b.) METEORIC IRON, EAST MT. MAGNET, MUR. DIV.

In his Annual Report for the year 1916 the writer gave a very brief account of a meteorite which had been found in that year and presented to the Geological Survey.\* This body was not seen to fall but was discovered by Mr. James Connors 6 miles east of East Mt. Magnet (Lat.  $28^\circ 10'S.$ , Long.  $118^\circ 30'E.$  approx.). Since that was written the meteorite has been analysed and etched so that more detailed particulars are now available.

As found, it was in two pieces, one large and one small, which fitted exactly together. It weighed in all 16.5 kilos ( $36\frac{1}{2}$  lbs.) and was of a peculiar sickle shape as shown in the accompanying illustration. Plate XXIII.

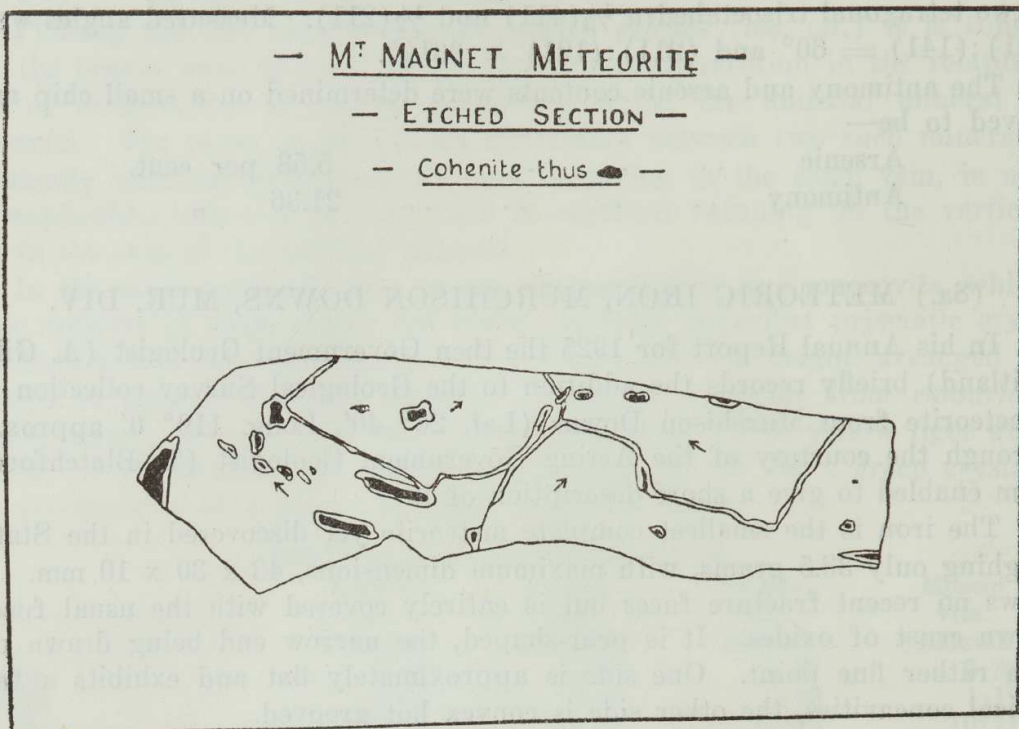
An analysis gave the following results:—

Fe	Ni	Co	P	C	S	Total	D
85.66	13.56	.77	.05	str ng traces	trace	100.04	7.967

\* An. Rept. Geol. Surv. W.A., 1916, p. 26.

Two polished and etched sections revealed an unusual structure. The surfaces exhibited first a broad subdivision, with irregular outlines to the segments, which reached from 5 to nearly 10 centimetres in diameter. These segments had a faint schiller of varying orientation, indicated by the arrows in the illustration, Fig. 3. They were outlined by narrow

Fig. 3.



Mt. Magnet Meteorite—Three-fifths natural size.

layers of schreibersite, occasionally including small masses of cohenite, and in places flanked on either side by a single rather broad (0.5 to 1.0 mm.) kamacite plate. This broad structure is best described as "brecciated."

The individual segments are very finely flecked internally, with no indication of Widmanstätten figures to the naked eye. With a low power (1 inch), however, the surface is seen to be composed of a mass of structureless plessite thickly strewn with short narrow (0.02 to 0.04 mm.)\* discontinuous plates of kamacite, with appreciable parallelism in three octahedral directions. Dotted very irregularly over the section are masses of cohenite never exceeding 8 x 3 mm. They are surrounded by a layer of schreibersite alone, or by a further layer of kamacite. See Fig. 3.

In the second smaller section the structure still appears coarsely brecciated with only a minute flecking to the naked eye, but with low power shows a background of plessite with a distinct octahedral arrangement of narrow kamacite plates having borders of taenite plainly visible. The whole structure is much more continuous, though the area occupied by plessite still preponderates. No troilite was seen in any section.

From the above description it is evident that the Mt. Magnet meteorite is a siderite which would be classified in Brezinas system as "finest octahedrite, brecciated," with the symbol "Offb." According to Farrington's classification it belongs to the Tazewell Group of finest octahedrites characterised by a nickel content exceeding 10.5 per cent.

\* The broader measurements probably representing oblique sections.